

YOUNG URANIUM

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Abstract

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Deposits of young (post-glacial) uranium are presently forming in a considerable variety of environments in Canada and the northern U.S.A. by interaction between soils or sediments and uranium-bearing groundwaters. The uranium tends to be loosely held, and as it is too recently deposited to have built up radioactive daughter products, concentrations are seldom detectable by scintillometer. Young deposits are of apparent economic interest in view of their common occurrence, amenability to in-situ leaching and lack of radioactive components. They are of environmental interest because they form concentrations of poorly fixed uranium which surface in areas of agriculture or development, and finally they are of academic importance for what they can tell us of how uranium accumulates in a sedimentary regime.

Introduction

One theory for the widespread occurrence of major uranium deposits near Lower Proterozoic unconformities is that these periods of erosion followed development of an oxidizing atmosphere in which labile uranium could be leached from previously exposed outcrops and clastic sediments. In the northern latitudes we are presently living in a somewhat comparable situation, however, in that the ice ages exposed vast amounts of fresh, unleached outcrop and pulverized detritus which are now uncovered in an oxidizing regime. It would hence not be surprising on theoretical grounds if this were an epoch of active uranium accumulation, and it is now clear that deposits of uranium are, in fact, forming with rapidity and variety. In the mere ten thousand years since glacial retreat, some have already reached a size and concentration

to be of economic interest. Their lack of wider recognition seems to be due largely to the fact that they have not yet developed radioactive daughter products and hence (with few exceptions) are not detectable by scintillometers. In addition to the economic aspects, these deposits are of academic importance for their models of how uranium deposits accumulate, and are of social significance as some involve reservoirs of poorly fixed uranium which surface in areas of agriculture or development.

Although the young uranium deposits vary widely in their appearance and modes of accumulation, those discovered to date have the following unifying characteristics:

- (1) They are surficial, forming at the surface or within a few meters thereof in unconsolidated materials. Deposits are likely also forming at depth, but exploration has not been directed at these.

(2) They are forming from the interaction of ground or surface waters with soils or sediments. The type of water involved and the mode of interaction or uranium entrapment form the basis for deposit classification.

(3) Almost no daughter products are emplaced with the uranium, and hence no anomalous radioactivity is associated with the deposits. Exceptions occur in cases of extreme surficial enrichment and in cases which directly involve fresh-water springs.

(4) The uranium is loosely held and easily remobilized.

(5) Molybdenum enrichment is commonly present, and some other elements are occasionally accumulated. No vanadium anomalies have been observed to date.

(6) Deposits virtually always occur in groups associated with granitic stocks or phases of larger intrusions. These are referred to as "donor" intrusions.

Description

In appearance, young uranium deposits vary from evaporite flats and alkaline lakes to northern bogs and alpine meadows. Understanding and classifying this spectrum depends firstly on understanding the difference in the way uranium is mobilized and demobilized in alkaline waters (Culbert and Leighton, 1978) as compared to fresh water.

In the accompanying classification scheme (Table 1), the mineralizing waters have been divided into alkaline-saline, alkaline and fresh. The first class represents trapped or slowly moving waters usually of tens of parts per thousand salinity. The "alkaline" class includes typical "hard" ground or small-flowage waters of arid or semi-arid areas, which are of alkaline pH and commonly high bicarbonate content. All three classes are capable of producing deposits of economic interest, but the types of trap and styles of demobilization are quite different.

The mechanisms by which humic materials extract uranium from fresh water are numerous

and complicated, involving forms of adsorption, reduction, chelation and complexing. A recent study by Schmidt-Collerus (1979) unravels some of the complexities. Functionally, these mechanisms act rapidly and are sufficiently effective that they can screen and concentrate uranium from large volumes of passing water whose uranium levels is only in the order of a few ppb.

These extraction mechanisms do not work nearly as effectively with alkaline or saline waters, however, for the following reasons:

(1) Uranium fixation by humic materials drops off rapidly at alkaline pH (Manskaia et al., 1956).

(2) Many of the organic acids responsible for uranium fixation are themselves soluble above a pH of 8.

(3) In waters which are not fresh, there is ion competition for adsorption sites (Lopatkina, 1967).

(4) Uranium requires substantially lower Eh levels to be reduced in an alkaline environment (Hostetter and Garrels, 1962; Langmuir, 1978).

(5) Waters with some salinity tend to be buffered against rapid changes in pH or Eh.

Normally, alkaline waters are more likely to leach uranium from their courses than deposit it. This is clearly demonstrated by the fact that within the areas of donor plutons, fresh waters produce uranium anomalies in organic stream sediments while alkaline waters usually do not, despite their much higher uranium contents.

Uranium traps for alkaline or saline waters therefore tend to be of a different nature, and in general are slower acting than the fresh-water cases. The higher uranium contents of alkaline waters, however, have allowed their deposits to reach the same size and grade. The fixation mechanisms involved are not well understood, but appear to include evaporitive entrapment, decomplexing (of uranyl carbonate ions) and chemical or biological reduction. The complicated reactions of brine diagenesis (Eugster and Hardie, 1978) are undoubtedly important in saline water deposits. Lowering of pH is also an

TABLE 1

Classification of young uranium deposits

Type of trap	Type of water		
	alkaline-saline	alkaline	fresh
Closed basin	Common. Evaporite environment. Fig. 1		
Cyclically flushed	Common. Organic layers. Fig. 2	Common. Upward increase in organic content. Fig. 3	
Spring-fed	Usually small. Fig. 4a	Fairly common. Small but rich Fig. 4b	Common. Usually small; sometimes radioactive. Fig. 5
Groundwater	Uncommon. Fig. 6a	Common. Assymetric. Fig. 6b	Common but small
Collection basin		Fairly common, often complex. Fig. 7	Common. Fig. 8
Valley swamp or lake		Fairly common. Roll-shaped or layered. Fig. 9a	Common. Roll-shaped or layered. Fig. 9b
Valley meadow		Rare, marginally alkaline Fig. 10	Common. Often in series
Channel obstruction		Dammed valley deposit. Likely rare. Fig. 11	
Lacustrine deltaic		Known cases of poor quality.	
Meadow, oxbow		Mineralized by side-drainages. Uncommon. Fig. 12	
Back-berm, levee		Likely uncommon. Fig. 13	

effective method of precipitating uranium from alkaline waters, and soils with a pH as low as 3 have been reported from young uranium occurrences by the British Columbia Department of Agriculture. The pH-Eh environment of uranium concentration in an English bog has been studied by Ostle and Ball (1973).

It has been shown by Szalay (1964) and others that peat is capable of concentrating uranium by a factor in the order of 10,000 times its level in the waters in which the peat is immersed. It is not uncommon for portions of young deposits to reach 1000 ppm uranium, which would require there to be 100 ppb in the passing groundwater at the above coefficient of

concentration, if no secondary enrichment mechanism is involved. This is an order of magnitude above what is found in fresh-water cases. Such levels are occasionally encountered in moving alkaline or saline waters, but in that regime the coefficient of concentration is much lower, as previously explained. In addition, many uraniferous layers are dominantly clays or marls which have lower capacities for uranium extraction, an order of magnitude lower than peats in the case of travertine (Serebrennikov and Maksinova, 1976). It hence appears that secondary processes within the deposits have already raised their grade in places by at least one order of magnitude. The nature of

these processes is not known and there are many possibilities, such as concentration by oxidation of organics or by transport attached to dissolved organic acids (Schmidt-Collerus, 1979). It is clear, however, that neither primary nor secondary accumulation mechanisms involve a tight binding of appreciable quantities of uranium, which instead remains loosely fixed.

Our exploration during 1978 and 1979 found young uranium deposits in southern and northern British Columbia, in the Yukon, in the maritime provinces and in the northwestern U.S. Reports of strong accumulations of young uranium have also been made from the Canadian Shield (Coker and DiLabio, 1979), Scandinavia (Armands, 1961) and Russia (Kochenov et al., 1965), as well as from a number of non-glaciated areas.

Levinson and Coetzee (1978) reviewed the implications of radiometric equilibrium in the surficial environment for radiometric uranium exploration. Surficial uranium deposits were discussed and many described in the report of the International Atomic Energy Agency Working Group on Surficial Deposits (IAEA, 1984). This paper will rely heavily on data from the Okanagan area of southern British Columbia. In part this is because these deposits were among the first recognized and are hence better known. More importantly, this information has been made public during reports to the B.C. Uranium Inquiry Commission and the B.C. Ministry of Public Health (Culbert, 1980) and by a preliminary extraction feasibility study for selected deposits tabled before that commission (Hunkin Engineering, 1979). This exposure and the subsequent ban on uranium exploration in British Columbia have removed any question of privileged information.

Before proceeding with classification and descriptions, it should be noted that all deposits have been sampled by extendable hand augers using half meter sampling intervals, so that cross-sections show only the coarser variations in uranium content.

In converting from parts-per-million ura-

nium to actual tonnage of U_3O_8 (or pounds per unit area), it is necessary to consider the in-situ density of (dried) sediment. This varies all the way from 1.6 g cc^{-1} or more for some saline clays to less than 0.5 g cc^{-1} for organic ooze or sphagnum. In general, inorganic sediments tend to be over 1.0 g cc^{-1} while the usual organic materials run somewhat under unity.

Classification and examples

The following classification (Table 1) is based on the type of water involved in a deposit and on the type of trap. It is not being proposed as a formal classification system for young deposits, but has proved useful both in discussion and in exploration. The classes are only descriptively defined, and tend to grade into one another. Furthermore, the number of deposit types and their relative importance are likely to change as exploration continues.

Closed basins

Hydrologically closed basins tend to become hypersaline, with minimal plant growth. Upward movement of groundwaters toward the surface (evaporative pumping) may therefore transport uranium without reduction to concentrate it at the surface. The example (Fig. 1a) from Wow Lakes near Oliver, B.C. is a classic in this regard. Surface enrichment of uranium here reaches 2000 ppm and although daughter product equilibrium is less than 2%, this still allows the deposit to be detectable by scintillometer. Surface concentrations in alkaline flats are subject to wind erosion.

Not all closed basins produce surface concentrations. Larger basins have dominantly lateral groundwater flow (rather than vertical), and brine pools may also cause decomplexing of uranyl carbonate at lower levels. Example 1b, again from Oliver region, shows a sediment-bottom accumulation in a lake whose sediments are dominantly gypsum, overlain by a purple culture of sulphate-reducing bacteria.

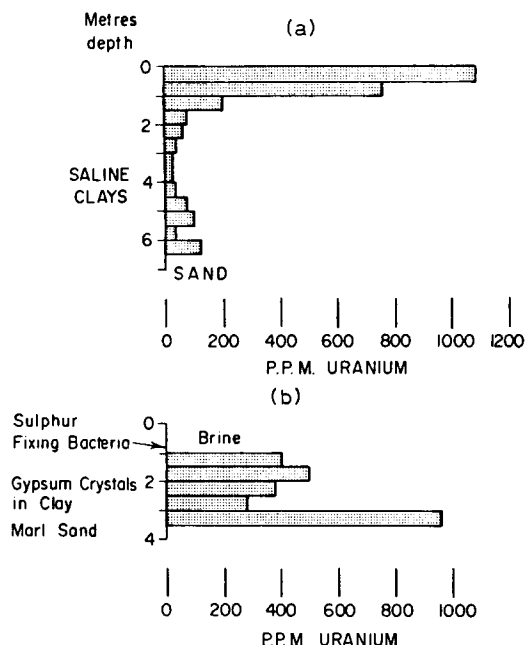


Fig. 1. Closed traps - alkaline saline. Sample profiles. (a) Oxidizing; (b) hypersaline, reducing.

Uranium carbonate complexes entering by groundwaters are either decomplexed by high salinity and sulphate acidity or reduced by the effect of the bacteria on the overall system.

If there are secondary concentrating mechanisms causing uranium deposits to form within the large, saline playas of the Basin and Range province, they have not been observed. Uranium in playa or evaporite environments has been studied by Bell (1955, 1960) and by Leach et al. (1980).

Cyclically flushed

Many saline or alkaline basins are only marginally closed and periodically flushed, the resulting episodes of fresher water leaving organic layers in the clays or marls. The result is typically a layered deposit, although the uranium concentrations do not always correspond to the organic sections. Localization may have more to do with H_2S generation, the name "Stink-

hole" locally applied to Fig. 2 deposit being indicative.

The Starvation Flats deposit (Fig. 3) of Stevens County, Washington is an example of a basin which has filled with sediments to the extent that flushing is now quite frequent. As a result, the sediments are dominantly marls in their lower parts and peats in the upper, and the waters are alkaline but of low salinity. The odour of H_2S is again strong in the lower peat layers.

Spring fed

Although upwelling groundwaters likely play a part in the formation of many young uranium deposits, some are clearly a function of a major spring and are characterized thereby. Where seeps occur below a saline lake or flats, the result will simply be a pod of concentration at that point (Fig. 4a) unless conditions permit a surface concentration. The Meyers Flats deposit of Fig. 4b occurs where Victoria Creek passes under porous glacial sediments and resurfaces below a swamp. This rising water appears to oxidize and destroy organics at the underlying sand-peat interface, further concentrating the uranium which reaches as much as 0.3% across half a meter. The upwelling is diffuse, and hence slow. Victoria Creek waters, which run 15–25 ppb uranium, apparently have sufficiently low salinity for adsorption-filtration to be effective at the organic boundary.

In the case of springs involving the initial surfacing of fresh water, radium and sometimes radon may accompany uranium; and radium has a strong tendency to be deposited near spring mouths (Culbert and Leighton, 1981). As a result, fresh-water spring deposits may, in part at least, be radioactive. An example from Bennett Lake area of the southern Yukon is shown in Fig. 5, where multiple springs along a major fault system have introduced uranium and radium to the organic accumulations of a sloping meadow.

Although usually quite small, fresh-water

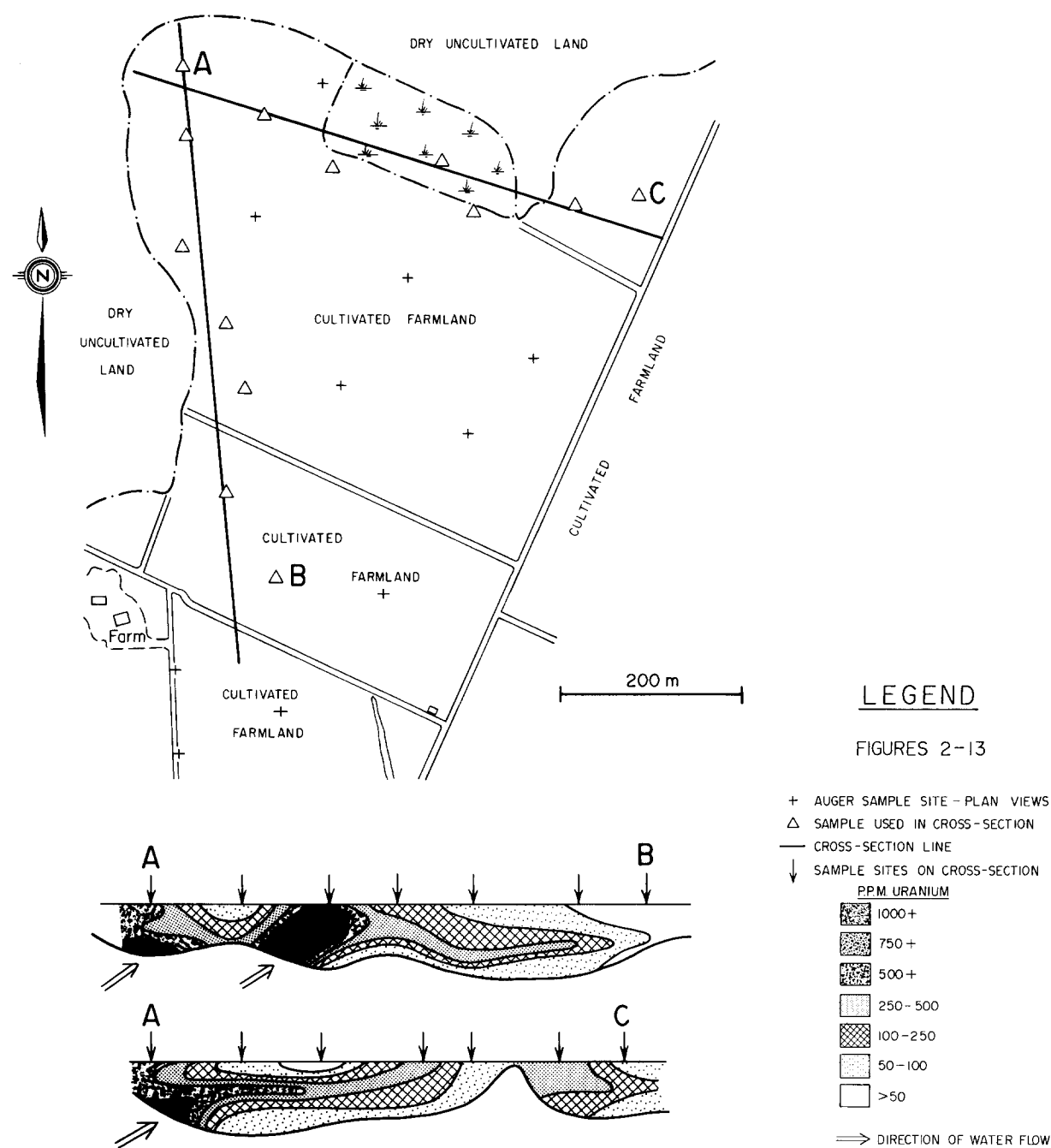


Fig. 2. Stinkhole Lake, Summerland area, B.C.

spring deposits are relatively widely reported due to their detectability by scintillometer. Examples are from Colorado (Malan, 1957; Schmidt-Collerus, 1979) and from Wyoming (Love, 1963).

Groundwater intersection

Most young deposits are fed to a major extent by groundwater, but this class is represented by sites where moving groundwater has simply

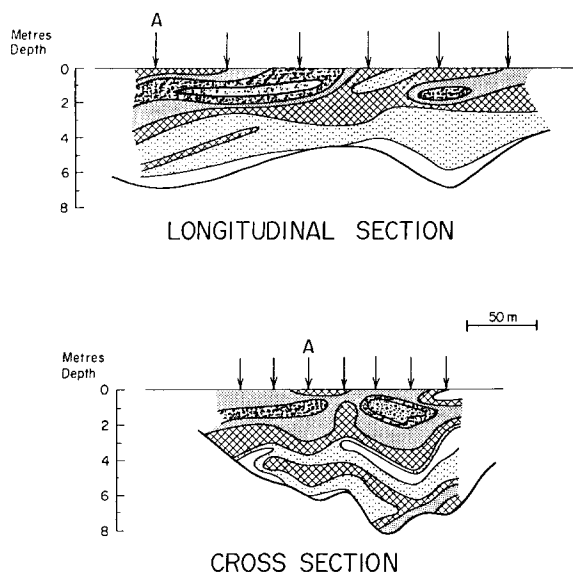


Fig. 3. Starvation flats, Washington.

been intersected by a dip in topography with resulting lake or marsh and organic growth. One feature of such deposits is their asymmetry, being richer on the inflow side, and with uranium elsewhere concentrated mainly along the interface of the organic materials with the underlying silt or sand. Deposits are also controlled by basal topography of the trap. Figure 6a shows

an unusual case in which there is bottom leakage from a sink in the down-flow side, leaving a well-defined uranium concentration in the up-flow basin and a profile without clear concentrations in the deeper sink. The alkaline water example (Fig. 6b) is a more simple and typical case.

Groundwater intersection deposits forming from fresh water tend to be small, as sufficient water flowage for larger accumulations would require surface drainage.

Collection basin

One of the most common sites of deposit formation is the collection basin, often near a valley head or valley junction, where both ground and surface waters are collected in a marshy bowl or lake with surface runoff. This runoff precludes development of saline waters, but sizeable deposits accumulate from both fresh and alkaline systems in this fashion. One such bowl is the Prairie Creek meadows in the town of Summerland, B.C. (Fig. 7). This "meadow" was once a marsh, but has been drained for agriculture and residential construction. Morphologically, collection basin deposits tend to

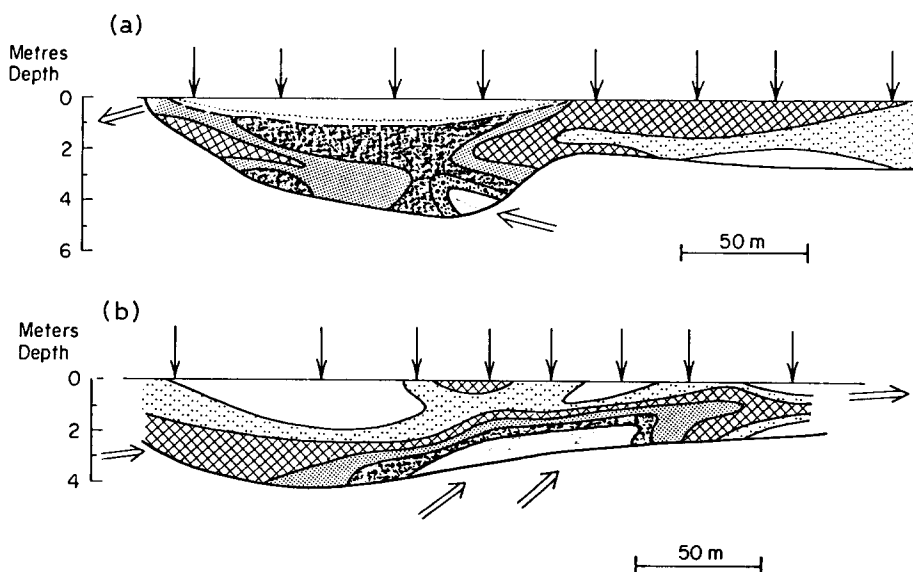


Fig. 4. (a) Ranchouse Lake, Oliver area, B.C.; (b) Meyers flats, B.C.

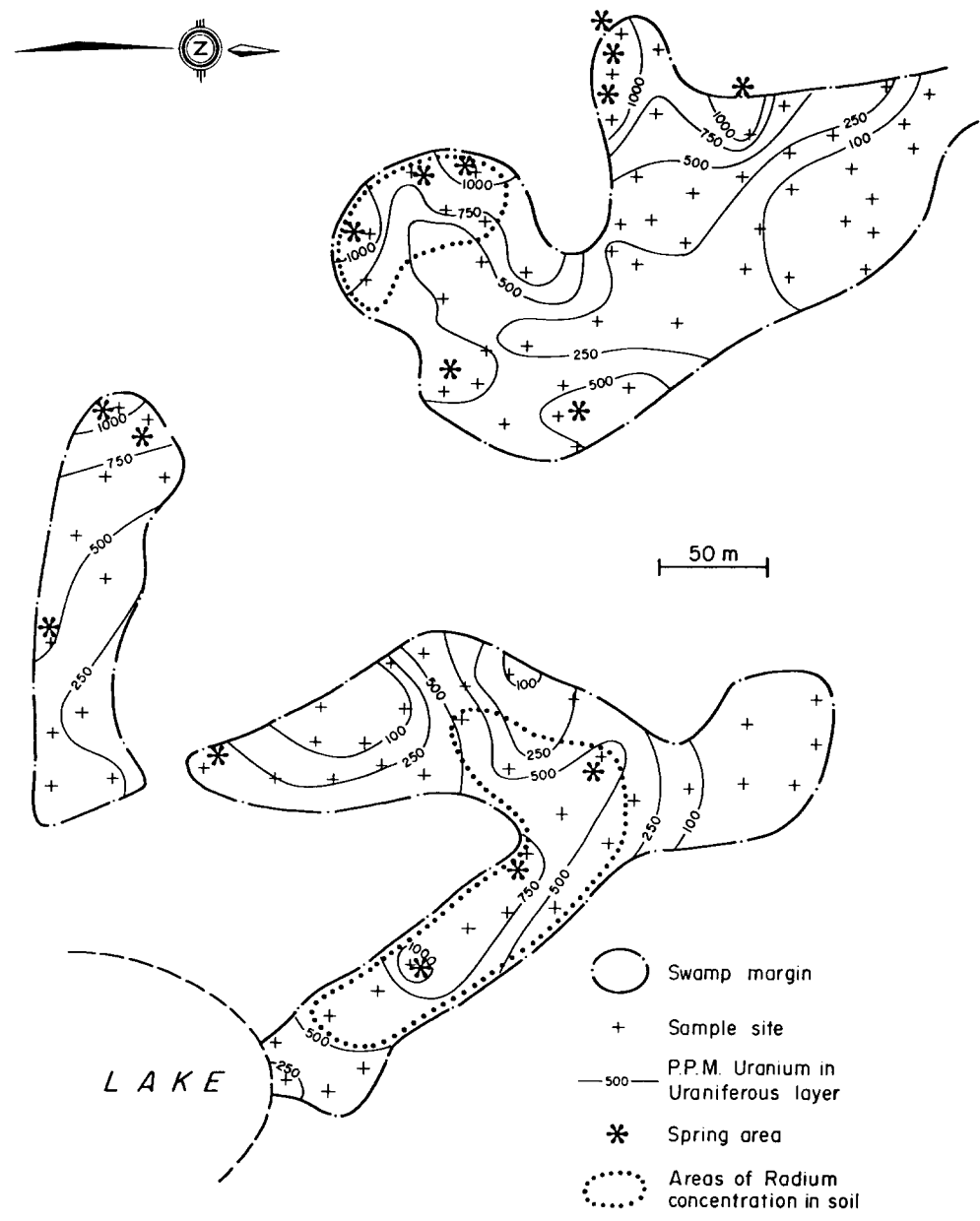


Fig. 5. Partidge Lake area, Yukon.

have complex drainage. Where the drainage is diffuse and its sources of variable uranium content, the uranium distribution will tend to be quite complex in plan view, as in Fig. 7. Where drainage is well-defined and of more homogeneous composition, uranium per unit area tends to depend more on the depth of organic profile and may be more regularly distributed, as in the

fresh-water Whooper Swamp deposit of New Brunswick (Fig. 8).

Valley swamp or lake

This style of deposit forms by partial damming or glacial excavation of a valley, and is one of the most frequent. Some occur in what seem

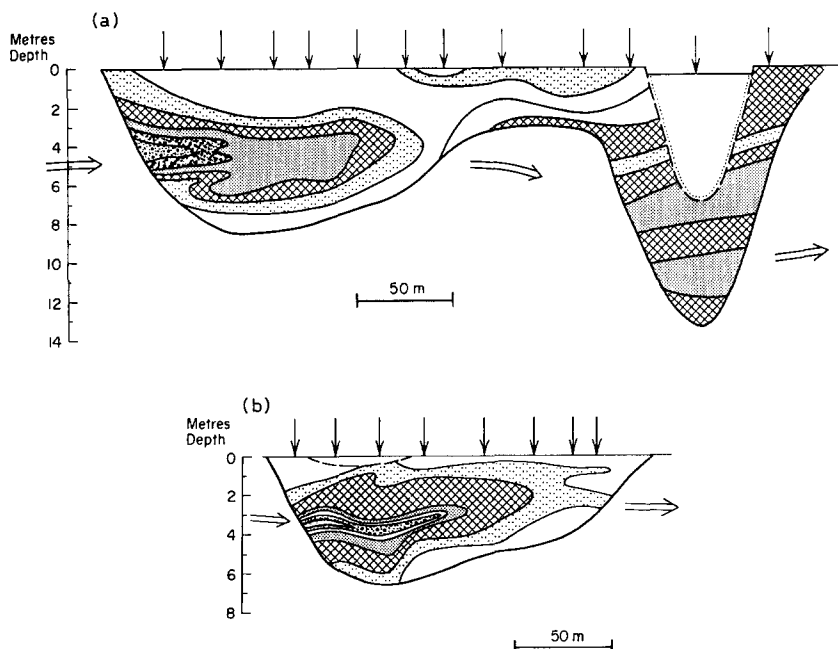


Fig. 6. (a) Sinking basin, Oliver area, B.C.; (b) Burnell swamp, Burnell Lake, B.C.

to be little more than historically common sites for beaver dams. They vary from the next class in a lack of a well-defined drainage channel, causing a more diffuse passage of water through the sediments and leaving fewer sand or gravel layers.

The deposits vary widely in shape, although there is usually a concentration of uranium at the upstream end. In some cases, both near-surface and near-base concentrations form behind this as the result of the free passage of waters on the surface and in underlying sands, resulting in an arcuate or "roll" shape of uranium accumulation. More commonly, concentrations are determined by interaction with groundwaters and with side drainages, such as in the Ruby No. 2 deposit of Pend Orielle County, Washington (Fig. 9b).

Where the water is sufficiently shallow for widespread growth of sphagnum or reeds, a layer of uranium may form near the level of decomposition of plant fragments. This may be due to the resulting reducing environment, or to the incipient production of humic and fulvic acids. The effect is apparent in the case of Fig. 9a,

showing a swamp bordering the Westbench suburb of Penticton, B.C.

Valley meadows

This style of deposit occurs where a uranium-bearing drainage crosses a marshy area. Uranium may be adsorbed to some extent from the central stream (especially as its course will shift across the centuries), but the major mineralizing solutions are usually from side drainages and underlying groundwaters. Valley meadow deposits tend to be erratic and often contain layers or channels of sand or gravel. They may also form in chains of concentration along a valley, the Lamb deposit of Idaho (Fig. 10) being an example. As adsorption-filtration from freely flowing waters is an important mechanism in this style of trap, it is effective in semi-arid areas only on the least saline and marginally alkaline waters. A more typical example is the Sand Lake deposit from the Trout Lake graben east of Atlin townsite in northern British Columbia. Published reports (Anonymous, 1978) indicated 4.7×10^5 lbs. of uranium in the

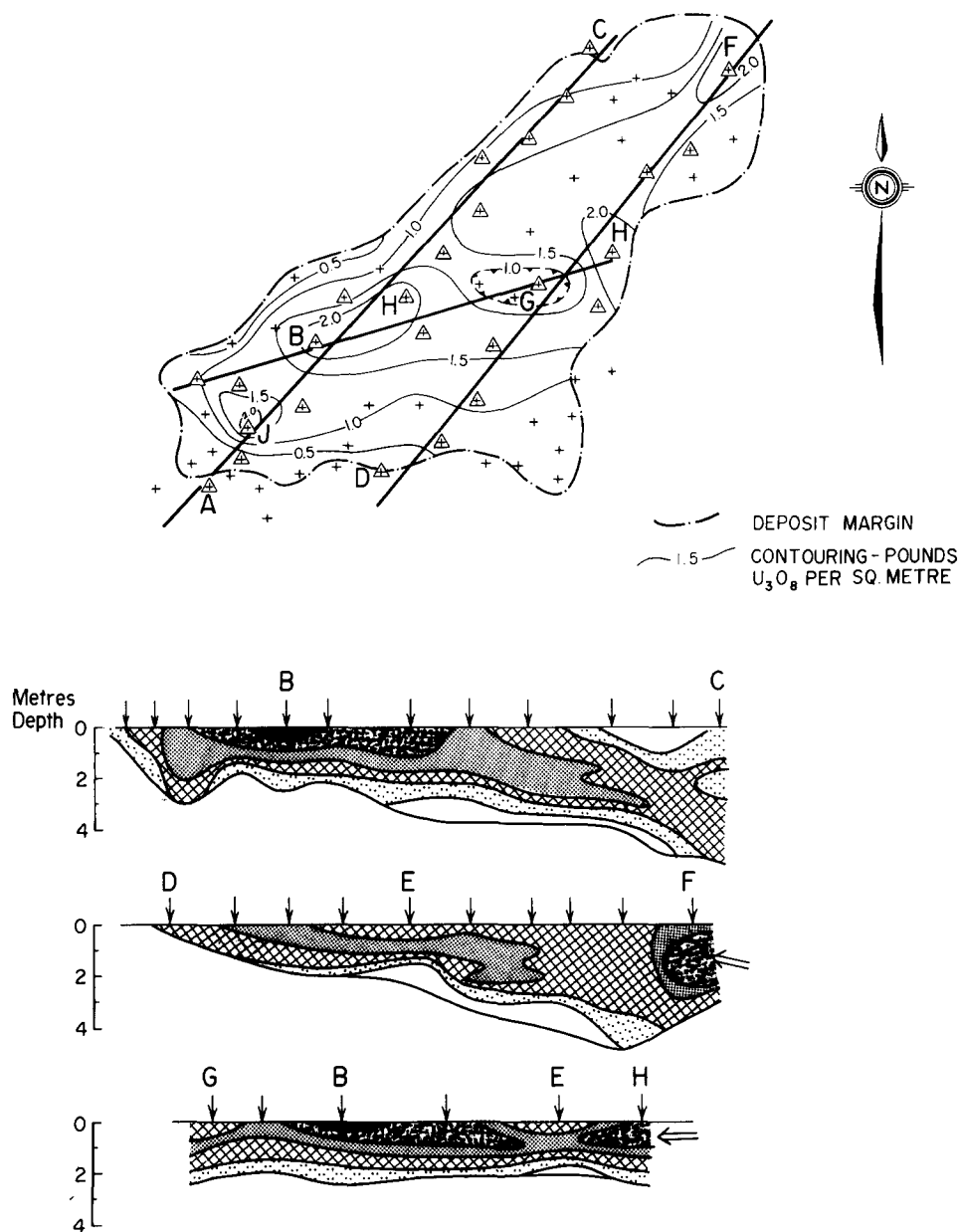


Fig. 7. Prairie Creek deposit, Summerland townsite, B.C.

marshlands adjacent to Sand Lake, with very little of the potential trap area in this region explored.

Channel obstruction

Channel obstruction bogs form where an otherwise swift and sandy creek course is dammed

by something fairly permanent, such as a landslide. The resulting long, thin marsh is eventually filled by peat and new sands flushed over top, but it remains as an effective trap. Such deposits are difficult to predict, and the Eneas Creek Canyon example (Fig. 11) (north of Summerland, B.C.) is the clearest one discovered to date.

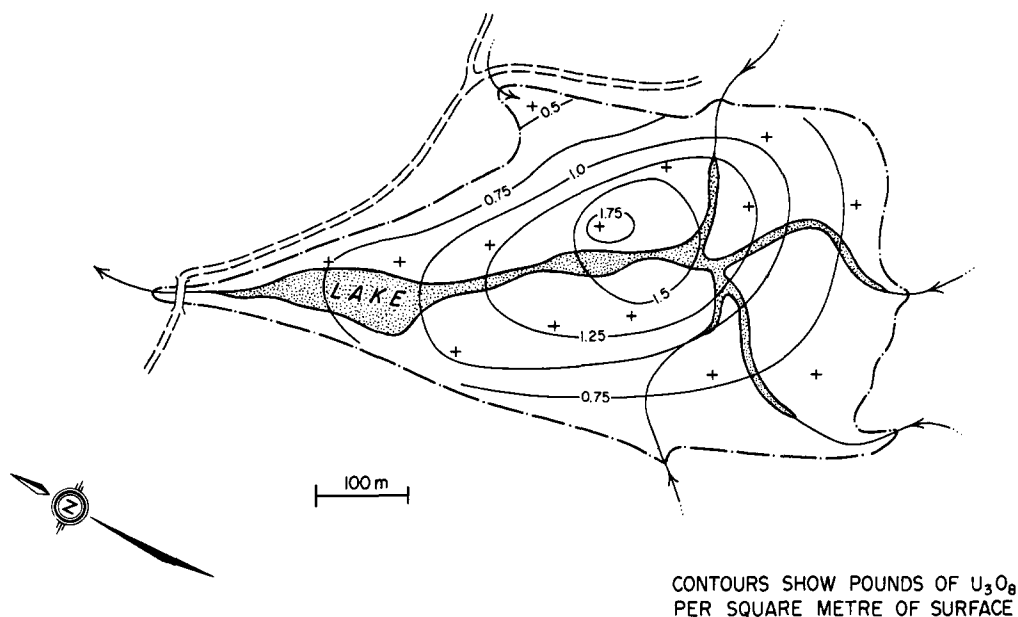


Fig. 8. Whooper swamp deposit, Dungarvan area, N.B.

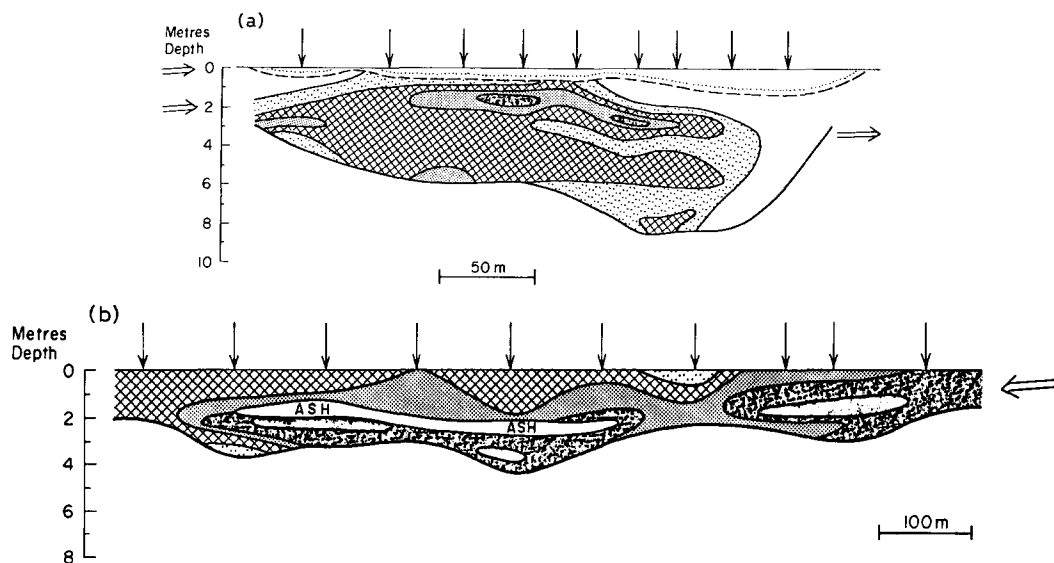


Fig. 9. (a) Nkwala Marsh, Westbench subdivision, Penticton, B.C.; (b) Ruby No. 2 deposit, Washington.

Meander or oxbow

Valley margin swamps, formed in abandoned meander channels along large rivers, represent the sedimentary environment quoted by several authors as typical for deposition of the sediments which host some styles of sandstone

uranium deposit. Our own observation is that large rivers are poor mineralizing agents, and such oxbow deposits as we have found tend to be the result of side drainages. In Fig. 12, an ancient meander in the Okanagan River, B.C. has cut into a glacial terrace. Uraniferous groundwaters passing through this porous ter-

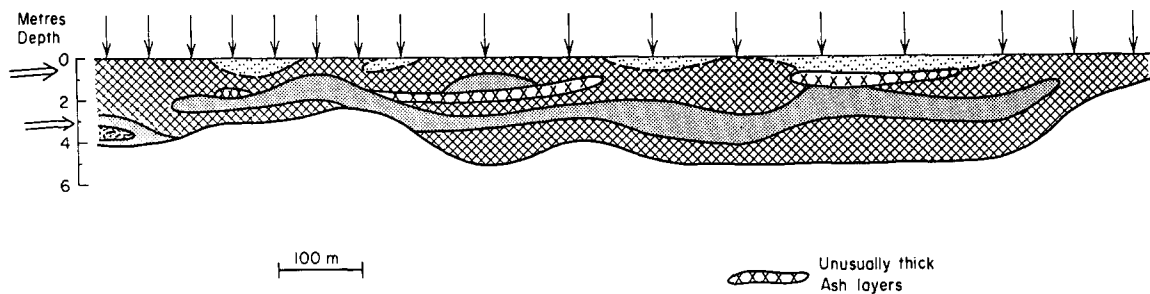


Fig. 10. Lamb deposit, Idaho.

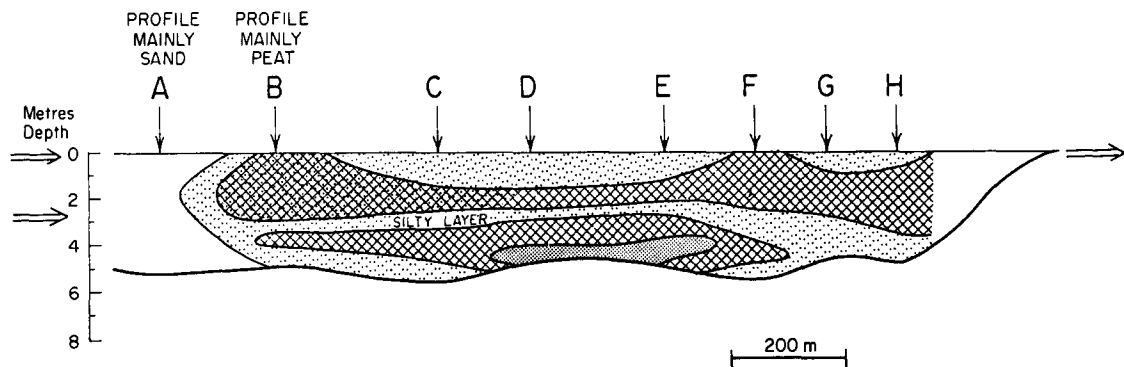


Fig. 11. Eneas Canyon, B.C.

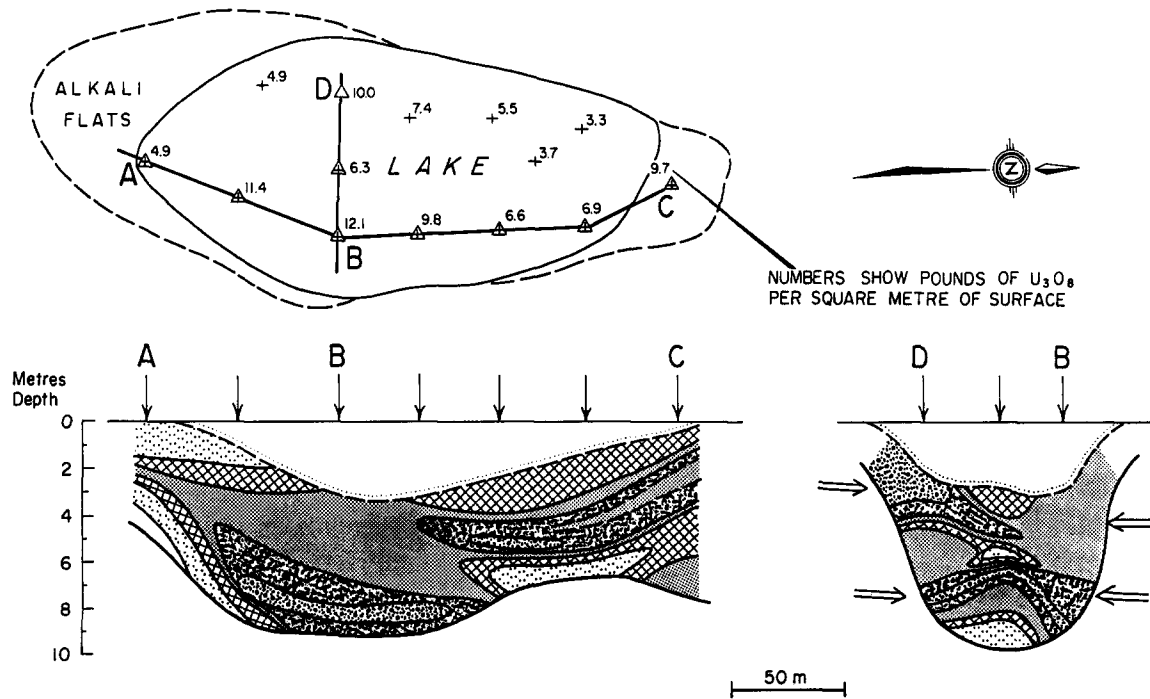


Fig. 12. Hunter basin, Okanagan River valley, B.C.

race are causing the deposit to form in a field used for production of vegetables.

Lacustrine deltaic

Deltaic marshes, where uranium-bearing ground and surface waters flow into a major lake, are an obvious site for deposits to form. Our observations to date, based largely on examples in New Brunswick, are that such deposits tend to produce evenly distributed uranium accumulations with few concentrations. Cases of economic interest have not been found as yet.

Back berm and levee

Swampy traps form when a side-drainage is blocked by a lake berm or river levee. An example of this (Fig. 13) is given from a mountain lake near the Washington-Idaho border, but the style is more classically found in windy and open areas such as Newfoundland, where wave action develops well-defined berms. As in the related deltaic case, there seems little tendency for uranium to form concentrations within the deposit.

Marginal marine

By theories of young deposit formations, where uraniferous springs or creeks feed into ocean-margin lagoons or organic basins should be ideal sites for uranium accumulation. In three areas tested along granitic shorelines of Nova Scotia there were higher concentrations in tidal peats than in adjacent fresh-water bog sedi-

ments, but no suitable marine trap has yet been found in the realm of a donor pluton.

Associated phenomena

Donor lithologies

Young uranium deposits almost invariably occur in clusters, occupying areas of several miles dimension, and associated with some pluton or phase of an intrusion. The donor lithologies themselves range from two-mica alaskites to heterogeneous hornblende quartz diorite, and no method of prediction has yet been found. Presumably it has to do with their content of labile uranium. Although almost all young deposits we have found to date are associated with waters draining intrusive rocks, this may in part reflect our exploration criteria. There are cases of post-glacial deposits elsewhere derived from sedimentary units (for example, Kochenov et al., 1965), and uranium rich waters are known to be associated with various lithologies.

Ash layers occur in the cordilleran deposits, and indeed Mount Saint Helens added a new layer to those of eastern Washington in 1980. There is no indication that these are a source of uranium, however, and although some uraniferous volcanic flows occur in southern British Columbia, we have found no donor tendencies amid extrusive rocks. A minor exception has been two deposits found over or near the Yellow Lake phonolite, a known uranium bearer (Church and Johnson, 1978), but these were specifically in an area where the lavas had been completely altered by hydrothermal activ-

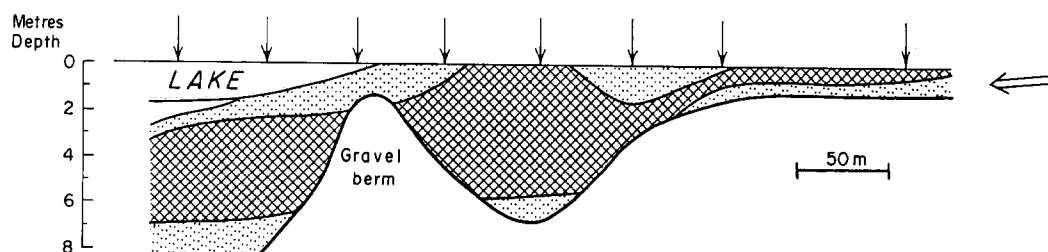


Fig. 13. North Skookum Lake, Washington.

ity. It is also of interest that foliated granites or gneisses have yielded no donor phases to date.

Some preliminary work by Boyle (1981) with tritium values for young deposit waters in northern British Columbia and young and Tertiary deposit areas in southern British Columbia suggest that the mineralizing waters are anomalously old. If this is true, the concept of a donor pluton may depend more on geopressurized or deep circulation portions of granitic terrain.

Disequilibrium

In the radioactive decay sequence of uranium, a thorium isotope known as ionium (^{230}Th) occurs near the beginning. Thorium is geochemically immobile in alkaline waters and neither it nor (more surprisingly) radium are concentrated in young deposits, with the exception of freshwater springs. Ionium's 80,000 year half-life assures, furthermore, that equilibrium will require a long time to be regained. Only a small fraction of the gamma radiation from the uranium series originates before ionium occurs in the sequence, and most of this is of too low energy to be detected by conventional scintillometers. Young deposits are hence, with very few exceptions, not marked by anomalous radioactivity and not detectable by scintillometers.

Recent concentrations of uranium would therefore appear to present the reverse of the tailings-pond problem, with radioactivity expected to increase across the succeeding tens of thousands of years, rather than decay away. The case may not be that simple, however. Routine uranium analyses in our work have been carried out by the low-energy gamma spectrometry (L.E.G.S.) technique (Culbert and Leighton, 1981) which also gives ^{232}Th (here an indication of detrital minerals) and the uranium daughter isotopes ^{226}Ra and ^{214}Pb . Based on these data, it appears that the uranium concentrations migrate slowly across the centuries; hence purifying themselves by leaving their

ionium behind. Under this view, young uranium deposits are too mobile to become radioactive unless fixed by dessication or by vanadium. Testing this theory, however, must await a down-hole version of the L.E.G.S. system to map uranium and its daughters in more detail.

Non-glaciated areas

Most of our exploration to date has dealt with glaciated areas. However, all that is necessary for surficial deposits of non-radioactive uranium to form is uranium-bearing waters which are moving, and a trap. The ongoing work of the National Uranium Reconnaissance Evaluation program has now demonstrated that uranium-bearing waters are not uncommon in the U.S. Cordillera. Our own research shows that the traps required in non-glaciated areas are somewhat different, accommodating slower accumulation over longer periods. These are not to be confused with the calcrete phenomenon (Mann, 1974; Carlisle, 1978) which is governed by the rules for mobilization and demobilization of carnotite, rather than the much more soluble uranyl-carbonate or urano-organic complexes.

The longer accumulation times for non-glaciated traps allow the possibility of substantially larger uranium concentrations to collect. For example, Benson and Leach (1979) have estimated that in the order of 4×10^8 kg of uranium may have been transported to the Walker Lake evaporation bowl (Nevada) in the last 2 m.y.

Older deposits

Another question of interest is to what extent the presently forming deposits may be used as models of syngenetic deposition of older sedimentary deposits. This is not a reference to roll-front accumulations, but rather to penecordant deposits and the sedimentary varieties common in Europe (Ruzicka, 1971; Barthel, 1974).

Certainly there are strong similarities in depositional environment to such cases as the Lodève deposit of France (Herbosch, 1974) and the Fakili of Turkey (Kaplan et al., 1974) and possibly the Todilto limestone of New Mexico. Initial considerations in this respect are that most fresh-water deposits form in too high-energy a regime to be stable over geological time. Alkaline and alkaline-saline traps stand a better chance of preservation, but even here remobilization seems likely if the deposit is not fixed in time by vanadium. It may prove that young, syngenetic uranium deposits are typical of environments which were source reservoirs of mobile uranium in sedimentary sequences, rather than the final site of deposition. More research is required in this direction. The recent suggestion that the major Australian proterozoic deposits of the Pine Creek geosyncline initially accumulated from saline groundwaters in an evaporite environment (Crick and Muir, 1979; Ypma and Fuzikawa, 1979) is important in this regard.

Associated elements

A major portion of the post-glacial uranium deposits tested to date contain molybdenum in concentrations of the same order of magnitude as uranium. Other elements such as selenium are also anomalous in some of the deposits, but not enough work has been done as yet on this aspect. Vanadium anomalies have not been observed to date.

It is not surprising that uranium and molybdenum should occur together, as both are transported by alkaline waters and immobilized by absorption or reduction. The uranium-molybdenum association in fresh-water accumulations was less expected, however. Test profiles have been analysed for molybdenum in several of the deposits, and results are shown in Fig. 14 for a variety of classifications. Although much remains to be studied, some tentative conclusions may be drawn.

(1) Some (probably most) uranium donor

intrusions are also molybdenum donors, while others are not. There seems to be no relationship to type of lithology.

(2) Fresh water is capable of producing molybdenum concentrations, although alkaline waters appear to be more effective.

(3) Where groundwater flow is lateral in a deposit, uranium and molybdenum layers tend to coincide, although some layers do not concentrate both.

(4) Where there is a vertical component to groundwater flow, molybdenum tends to be demobilized slightly before uranium. This is in contrast to the relationship observed by Harshman (1974) and others in roll-front sandstone deposits where molybdenum appears to have travelled farther than the uranium.

Environmental aspects

Young uranium accumulates in flat-lying areas, usually with organic soils and a water table at or near the surface. Clearly this will conflict with agriculture and with development. The illustrations of Figs. 7 and 12 show this problem clearly. (The rectangular ponds in Fig. 12 mark where peat was quarried for sale.)

The possibility of a public health risk appears to be two-fold. The first involves direct assimilation of uranium by crops and animals, a problem being studied by the British Columbia Ministries of Agriculture and Health.

The second and perhaps more difficult aspect is that most of the uranium is very loosely held, and could be mobilized by changes in land use. Extraction tests by Pyrih (1979) on some of the British Columbian deposits showed that a major portion of the uranium could be mobilized by a change of as little as one pH point. In the case of the Prairie Flats deposit of Summerland (Fig. 7), this would be flushed through the townsite area into Okanagan Lake, and the half million pounds of uranium involved could clearly "pollute" an immense volume of water under the present criteria for "safe" levels in waters. It is not implausible that extraction of

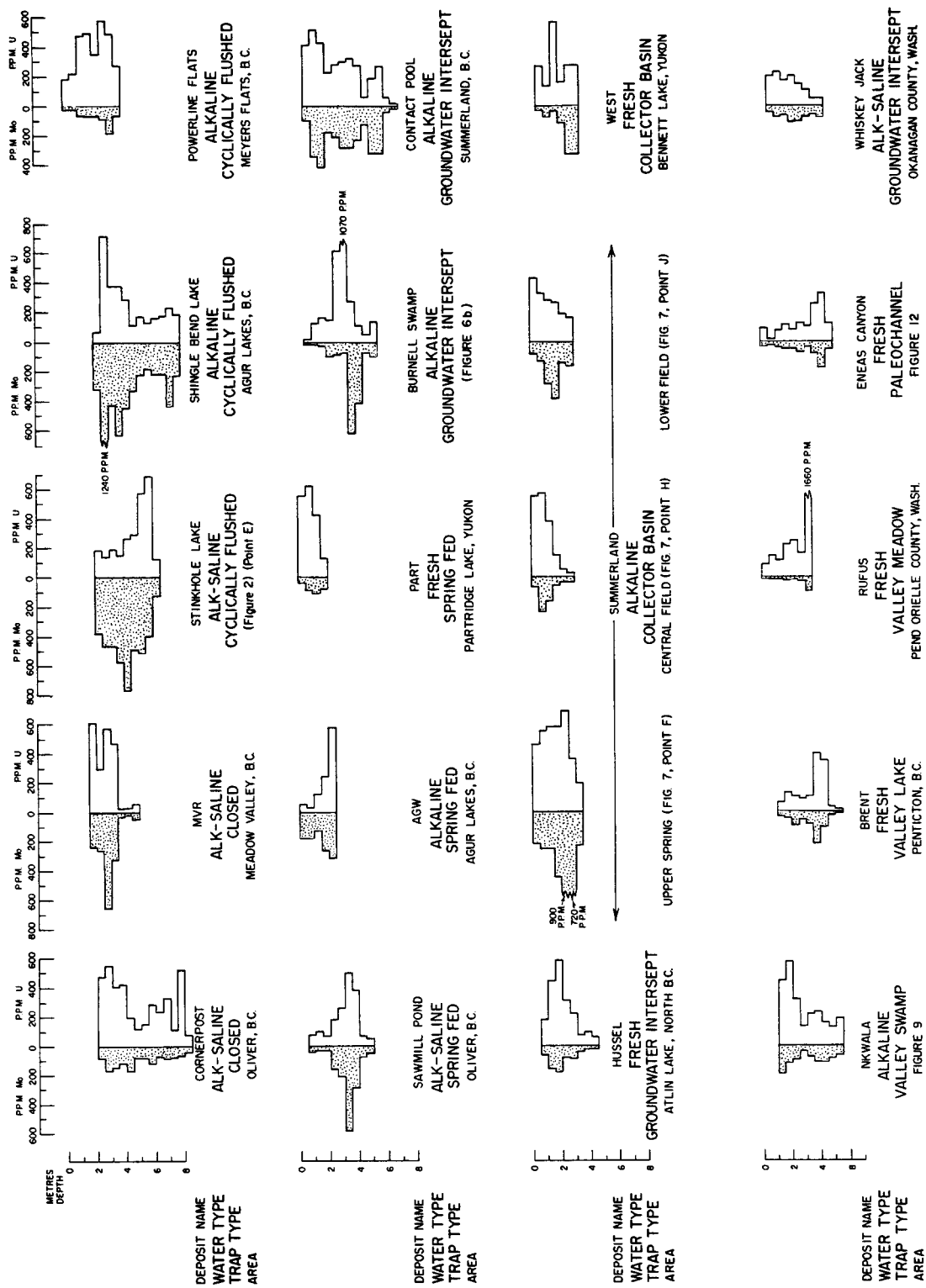


Fig. 14. Comparison of uranium and molybdenum profiles in selected auger holes from different deposits.

some deposits may eventually be undertaken as much on the grounds of public health as due to their own economic value.

Economic logistics

The economic aspects of exploration, evaluation and extraction of young uranium (and molybdenum) deposits are profoundly different from other classes of uranium ore. The following are the major points.

(1) Exploration and evaluation are done entirely by hand-auger. There is no expensive drilling phase. Acceptable tonnage estimates for most deposits require less than ten man-days field work.

(2) Being loosely held in soft, surficial soils or sediments, the deposits appear well suited to in-situ extraction (Hunkin Engineering, 1979) with mobile plants.

(3) Having no daughter products, there is no tailings problem or need for dealing with radioactive materials. As the uranium is already on the surface, there is no problem with having "introduced" it to the environment; in fact, it is being removed therefrom. Site development is therefore largely restricted to control of groundwater for traps which are not hydrologically closed.

(4) Plant mobility and low site development costs mean that to a major extent deposits in a region may be considered accumulative in uranium tonnage. Exploration is therefore aimed at accumulating deposits rather than looking for the one big one.

(5) Not only is size not as critical as for normal deposits, but neither is grade. In the final analysis the viability of any given deposit will likely depend on many factors, including hydrology, vegetation coverage, land use, and the nature of uranium fixation. Insofar as the concentration of uranium is concerned, the most important statistic will likely be the pounds of uranium per unit area of trap surface, together with the depth to which leaching must be done.

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